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C. BOONE AND C. E. BRENTON.

SOME INVESTIGATIONS OF COMMERCIAL TELEPHONE TRANSMITTERS.

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SOME INVESTIGATIONS OF
COMMERCIAL TELEPHONE TRANSMITTERS

by

CHARLES BOONE

and

CHARLES ELMER BRENTON

A Thesis Submitted for the Degree of

BACHELOR OF SCIENCE

Electrical Engineering Course

UNIVERSITY OF WISCONSIN

1905

INTRODUCTION.

Great strides have been made in telephony since 1876 when Alexander Graham Bell obtained his first telephone patents. More especially has the telephone been put to use in cities, towns, and prosperous communities. In our north-central and eastern states telephone wires connect long chains of country residences. These are woven into a network with the cities and town as centers. Except by the great Bell Telephone Company, little attention had been paid to connecting these centers with wires for talking purposes until within the last two or three years.

Although this wave of centralization is still spreading and growing larger, nearly every telephone company is turning its attention toward building lines and apparatus which will transmit speech over 300 to 1,000 miles. We now talk from Omaha directly to Boston, and from Minneapolis to New Orleans. Last year closed and this has opened with the Illinois Central and the Chicago, Burlington & Quincy Railroad Companies experimenting, and investigating the advisability of using the telephone instead of their telegraph systems. Because of the importance of most railroad messages, it is required of such a system that the operators

at the terminals of the line farthest apart be able to call and understand each other's conversation very distinctly. It was due to this demand for apparatus which could be relied upon for long distance transmission that we thought it desirable to make tests on some commercial transmitters.

OBJECT. In these investigations it was desired: first, to determine the clearness and quality of transmission for certain commercial transmitters, when the secondaries of their respective induction coils were connected in series with various values of impedance; second, to measure the power of these transmitters.

ARTIFICIAL LINE.

It was attempted to make the impedance as nearly equivalent to that of an actual telephone line, composed of two, No. 9 B. & S. gauge, copper wires, strung eight inches apart, as was possible in the time at our disposal for its construction. The self-inductance L of the line was calculated from the equation:

$$L = .7416 \log\frac{2a}{d} + .08 \text{ millihenrys per mile of}$$

wire, where a is the distance between wires and d the diameter of the wire in inches. The capacity K was computed from the equation:

$$K = \frac{.0194}{\log\frac{2a}{d}} \text{ micro-farads per mile of wire.}$$

The resistance of the wire was taken from Roebling's Tables and equals 4.165 ohms per mile at 75°F. The other constants amounted to:

$L = .167$ millihenrys and

$K = .00904$ micro-farads per mile of wire.

In an actual line the self-inductance and capacity are evenly distributed throughout the length of the line. In the construction of an artificial line this uniformity of distribution can be approached by the insertion of self-

inductance and capacity at sufficiently short intervals. According to Prof. Pupin,* these intervals should not be longer than sections which correspond to one mile of actual line. Since it was desired to construct a system that would be the approximate equivalent of at least 500 miles of actual line it was deemed inadvisable, owing to limited time, to make self-inductance and capacity for insertion at shorter intervals than 50 miles.

Enough No. 29 B. & S. gauge cotton insulated, copper wire was wound on wooden spools to give the 83.5 mil-henrys required. To this was added about 140 ohms of No. 36 B. & S. gauge German Silver wire, wound non-inductively, to complete the resistance of 208 ohms, corresponding to 50 miles of actual line wire. For the capacity, amounting to .93 micro-farads for every 50 miles of line, telephone condensers of approximately 2 micro-farads each were divided in such a way as to give the desired capacity.

The artificial line was built in sections whose constants differed from those of an actual line 100 miles long only in the concentration of self-inductance and capacity. Figure 1 shows the method of construction and connection

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*A. I. E. E., Vol. 17, pages 443-460.

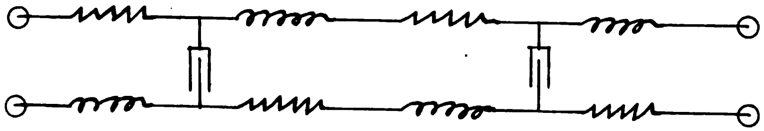


Fig. 1.

Five of these sections were made and during the progress of the tests as many of them were placed in series as would give the desired amount of impedance. At the end of each section taps are numbered 1, 2, 3, etc., and when referred to herein by section or number it will indicate the number of sections in series.

The self-inductance was measured by means of a Rowland Electro-Dynamometer and a standard condenser, and the capacity determined by the comparison method, using a ballistic galvanometer.

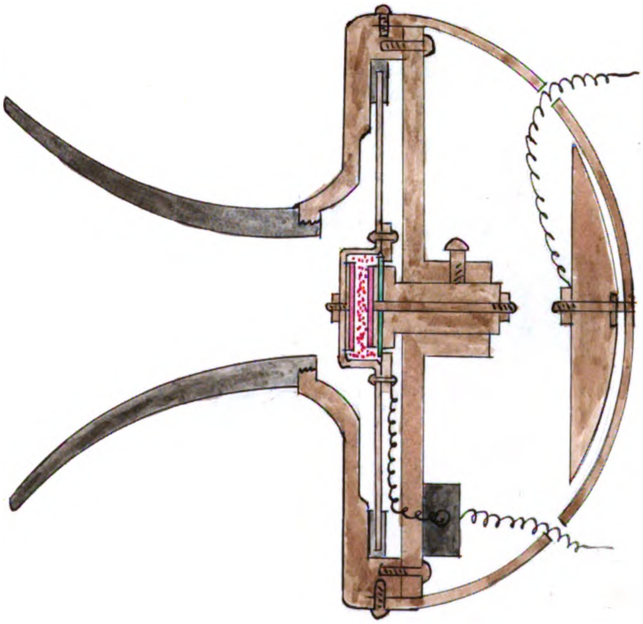
TRANSMITTERS.

Six transmitters were tested. They and their respective induction coils were furnished us by the following companies:

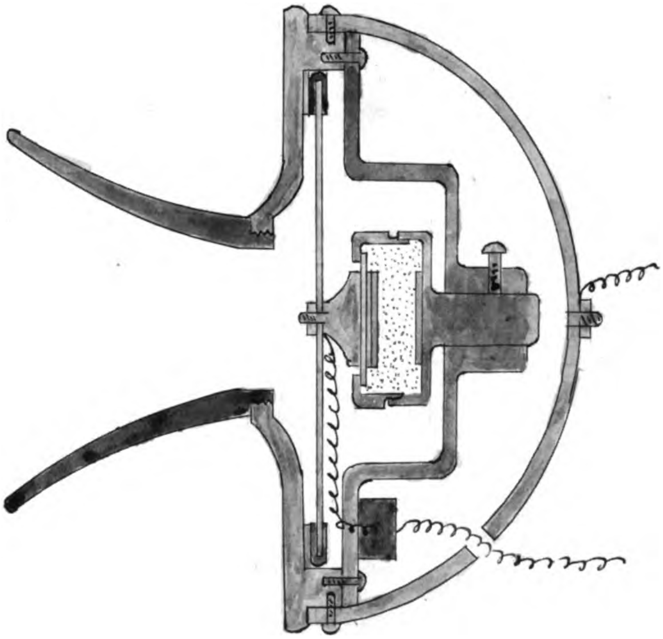
No. I, Kellogg Switchboard & Supply Co.,
No. II, American Bell Telephone Co.,
No. III, (Milde) Standard Telephone Co.,
No. IV, " " "
No. V, American Electric Telephone Co., and
No. VI, Eureka Electric Co.

All are of the "solid back type", except No. III, which is of the "button type". Peculiarities of construction can best be seen by a study of the accompanying drawings. The following color scheme is used:

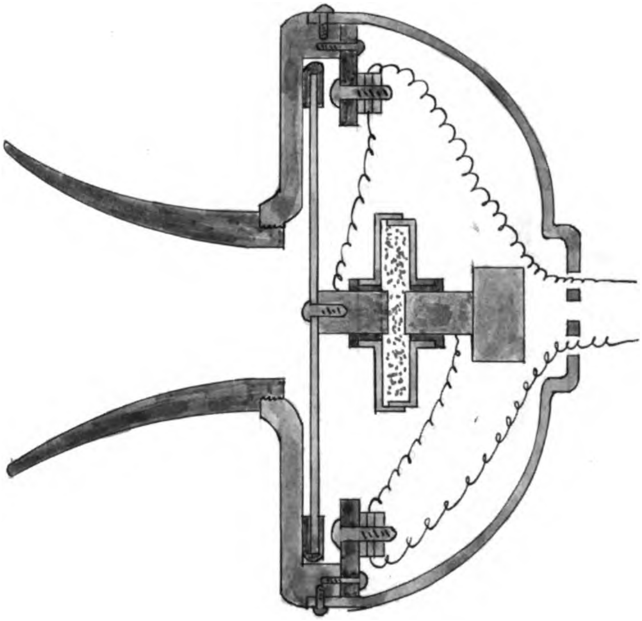
■ Metal
■ Insulation
□ Mica
▨ Carbon
░ Carbon Granules.



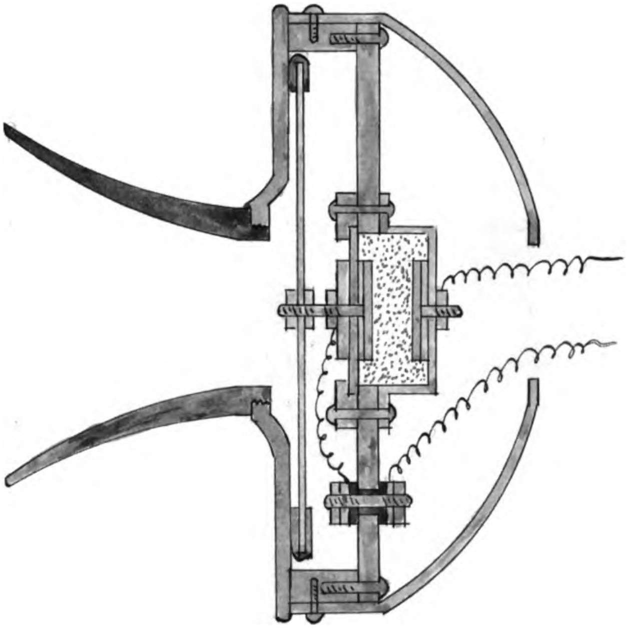
No. I.



No. II.



No. III.



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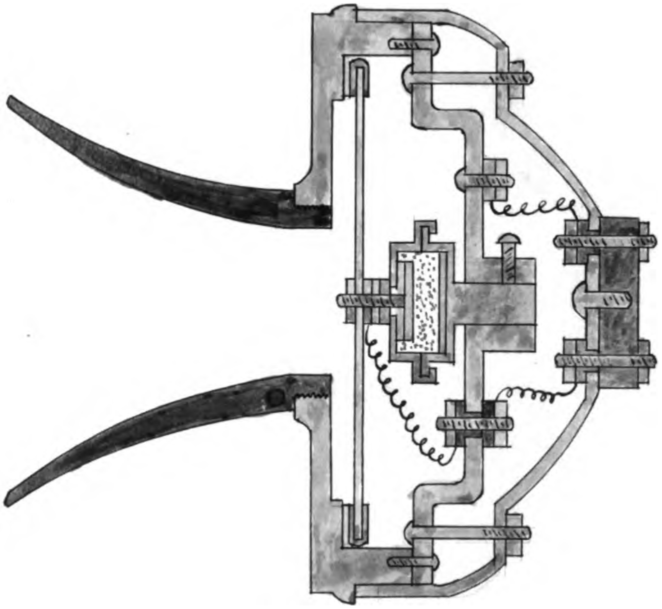
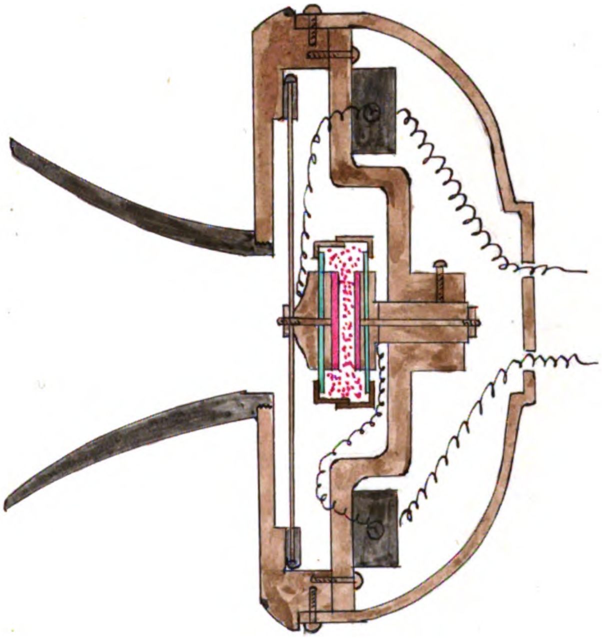
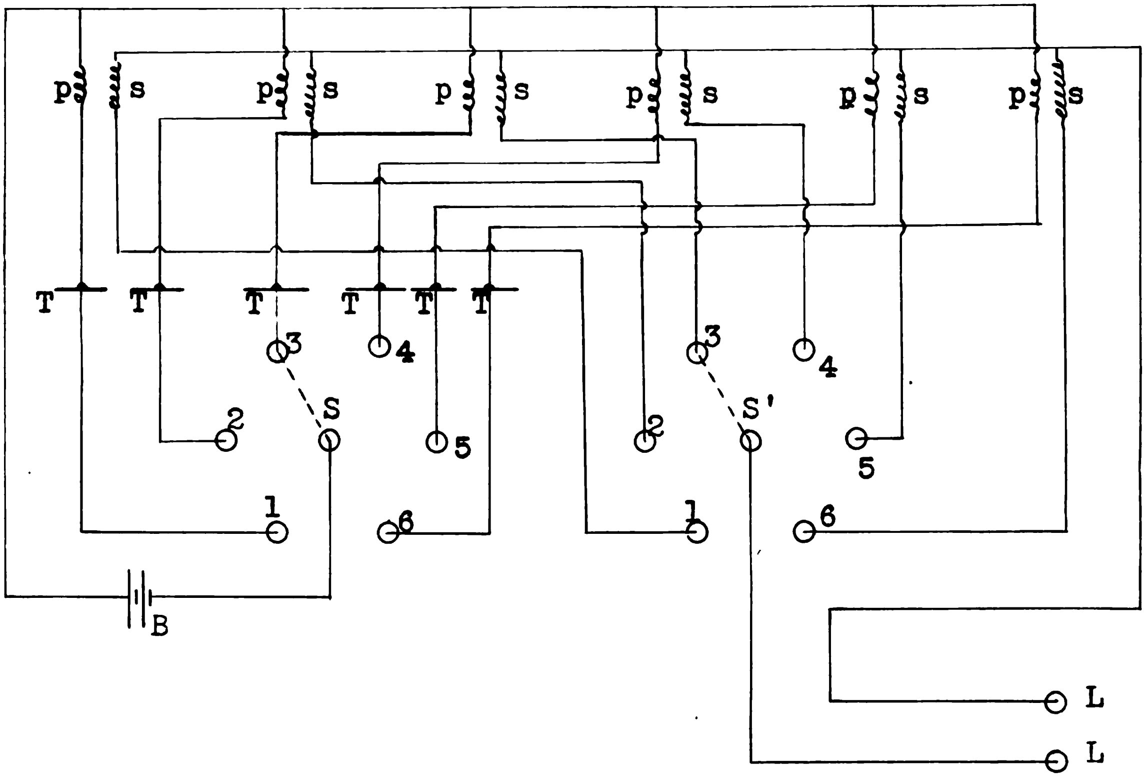


No. V.



No. VI.



SS', mercury switches.

p, primary of induction coil.

s, secondary of " "

T, transmitter.

L, artificial line terminals.

METHODS OF TEST.

CLEARNESS. Connections were made as shown in diagram on page 12a so that by aid of switches S and S' any transmitter with its induction coil could be thrown on the line terminals.

The clearness was determined by one person pronouncing lists of words into the transmitters and requiring a second person at the receiver to write them down. These lists, of about 40 words each, contain words of similar character. A sample list is shown on pages 22 to 29 inc.

Each transmitter was subjected to four tests at the end of each section as they were successively placed in series. A double pole receiver was used for all the tests. Each man transmitted two lists of words. In order that it would require the receiver to write his first impression of the identity of each word, they were pronounced as rapidly as he could conveniently write them down. The man at the transmitter held his mouth as closely to the instrument as would permit him to easily talk into it, and endeavored to speak all words in a uniform tone of voice. The man at the receiver held his instrument in such a position as to get its maximum effect.

The percentage of words correctly received is taken as a measure of the clearness of transmission.

QUALITY. The quality of transmission was determined by reading selections from newspapers into the transmitters, the person at the receiver judging the quality. These selections of about 200 words each were read into each transmitter and with all connections of the line sections the same as were used in the tests for clearness. Although the same selection was used but once,an endeavor was made to procure selections whose language carried the same general characteristics. The person at the receiver was kept in ignorance of the number of the transmitter under test in order that he could give an unbiased judgment.

In all the work the battery power consisted of two, type V, Edison-Lalande, closed circuit cells, connected in series, which furnished a potential of 1.7 volts.

MEASUREMENT OF POWER. The power of the transmitter is the ratio of the current flowing in the secondary to that in the primary circuits. The current in the primary is readily measured by means of a milliammeter. The current in the secondary is very difficult to measure: first, because it is very small, being something less

than $150x10^{-8}$ amperes for usual frequencies*; and, second, because it is an alternating current of a frequency ranging between 500 and 2,000 cycles per second.

Because of the high frequency, to measure this current is required an instrument free from self-induction, or its coils so wound that reactive effect is compensated. Some experimenters have used a very sensitive quadrant electrometer# with the aid of a powerful induction coil, and others have used a sensitive electro-dynamometer. Because of reactance due to self-induction in the necessary coils, they could expect nothing other than comparable results.

The seemingly most simple and accurate method is proposed by Dr. A. E. Kennelly. Dr. Kennelly° suggests the use of a Fessenden barretter. This consists of a short very fine platinum wire. It is obtained in a small cylinder of silver. In Dr. Kennelly's work, he soldered a piece of this wire to a couple of electrodes, dissolved the silver off of the platinum, and mounted the whole in a glass tube. The glass tube and mounting served to protect the fine

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*Paper by M. Wien, Annalen der Physik, Vol. 4, p. 456.
#Thesis 1896, by A. H. Ford for E. E.

°Paper before the International Electrical Congress, St. Louis, Mo., 1904.

wire mechanically. This connected in the secondary circuit of a telephone system is also made one arm of a Wheatstone's bridge as shown in figure 3. A and B have a resistance of 500 ohms each and are wound inductively. D is resistance of about 100 ohms of copper wire also wound inductively. These are thus wound so as to choke off the alternating current from the line which attempts to pass through the bridge instead of through the platinum wire. R is a variable resistance. C is a condenser which keeps the testing current from passing around the telephone line. Without action on the line the bridge is brought to a balance. Then by means of a horn or organ pipe placed at the mouth of the transmitter and blown by a source of constant air pressure the feeble alternating current is caused to pass through the secondary, heating up this platinum wire,

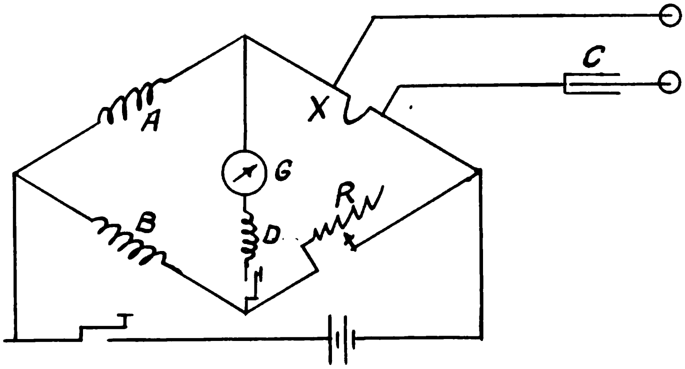


Fig. 3.

causing its resistance to rise, thus throwing the bridge out of balance. The bridge is then balanced for this new condition and, from the rise in resistance of the platinum wire, a measure of the secondary telephone current is obtained.

In Appendix I of Dr. Kennelly's paper above referred to, he proves that for "small alternating currents the change in resistance of the barretter is proportional to the square of the strength of the superposed alternating current". Thus,

If I = strength of the steady direct testing current,

i = effective superposed alternating current,

r = barretter resistance when heated by steady testing current I,

Δr = increase in r due to i,

c = barretter constant,

then $i = \sqrt{\frac{\Delta r}{r}} \times c$.

$c = \sqrt{b - I^2}$, where b is an approximate constant for a certain barretter.

If p = the power dissipated by the barretter when traversed by a steady direct current,

$b \doteq \frac{dp}{dr}$, and might be obtained by dividing the

increase in power consumption by the corresponding increase in resistance.

The writers attempted to follow out this method. Two coils were wound inductively with No. 29 B. & S. cotton covered copper wire, carefully insulating the turns with paper and varnish. These coils each have a resistance of 647 ohms, and were designed to be used in the arms of the bridge, A and B, in the figure. Another coil was similarly wound with about 480 ohms of the same wire in two pieces of about 240 ohms each. This was designed for use in the galvanometer circuit and allows a ready change of impedance. All coils were provided with iron cores to give an easier path to magnetic lines of force and thus increase self-induction.

Following the advice of Dr. Kennelly the University obtained for us 12" of silver wire with platinum core .000029" in diameter from W. & L. E. Gurley of Troy, N. Y.

A piece about 1" long in "U" form was soldered to two stiff copper terminals amd mounted in a cork stoppered test tube as shown in figure 4.

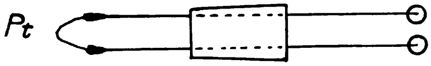


Fig. 4.

Holding to the cork, about 5 mm. of the silver wire was dipped in weak nitric acid to dissolve the silver off the platinum. Action took place quite slowly as we could see with the naked eye, or a little better with the aid of an eye-piece. Since platinum is not dissolved by nitric acid we looked for the action to cease which would be the signal to wash off the acid. The action did not cease until at the peak of the bend the wire was completely eaten through. A half dozen such attempts were made, but we only were able to get three to hold together any appreciable length of time. These were very carefully washed in water and layed away to be used a few hours later for the desired purpose.

Upon returning we found all but one broken. This was placed in an Anthony bridge with the induction coils inserted in the proper places, and its resistance was found to be only about .3 ohms whereas the resistance of Dr. Kennelly's platinum loop was 125 ohms.

This indicated that the remaining wire could not be in the desired condition. It was examined under a microscope and the sketch in figure 5 shows its appearance. ggg are transparent globules. The core down through the

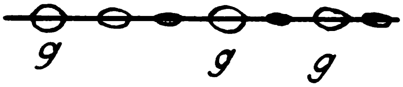


Fig. 5.

middle appeared to be the wire and no change was observed along its full length except a very gradual difference in size as terminals were approached and here globules ceased to be present. These globules could not be metal although they might be a salt of the metal which would aid conductivity. They might be due to impurities in the acid used, and also, if the acid had in it traces of hydrochloric or sulphuric acids, or some other impurities, it would then act upon the platinum.

We therefore obtained some chemically pure, slightly weakened, nitric acid. With an attempt to dissolve the globules from this wire it was eaten through. Several more were tried, but before the resistances could be gotten above .5 ohms they also ruptured. Thinking perhaps cork was not stiff enough to hold terminals stationary, causing stresses in the platinum large enough to break it, we mounted one on two fine copper wire terminals about four inches long. After very neatly soldering the silvered

wire about 1" long took the form of a nearly perfect "U". After holding it in the acid for a half hour, carefully keeping the action uniform, it also was broken.

The broken parts were then placed in the acid and as far as could be seen with the naked eye, they were completely dissolved. Although the wire as seen through the microscope appeared to be intact and not eaten, which would indicate that it was the desired wire, this last test showed that the wire was made of a material which would dissolve in nitric acid when left there long enough.

We conclude that either at some places the platinum wire might not have been intact,or that the silver and platinum were alloyed, or both.

Because of the failure with this quality of silver covered platinum wire and limited time, further attempts to measure the current in the secondary curcuit of a telephone system were abandoned.

RESULTS.

Results for clearness are tabulated as shown on result sheet No. I. The total number of words pronounced to each transmitter over each section of impedance, the total number correctly received and the percentage correctly received, are given. A discussion of the quality is given on pages 33 and 34.

The following is a sample list of words as given and received in the determination of clearness, the impedance being that of 3 sections in series:

Transmitter No. I.		Transmitter No. II.	
Given.	Received.	Given.	Received.
played	laid	paid	paid
acid	acid	rancid	----
trapezoid	trapezoid	cycloid	inlaid
florid	florid	horrid	------
threefold	threefold	scaffold	scaffold
upland	attend	mainland	mainland
offend	ascend	bland	dreampt
pound	-----	wound	wound
outward	upward	onward	onward
efface	-----	embrace	embrace

hinderance	hinderance	cumbrance	------
amiable	-------	agreeable	agreeable
constipate	constipate	alternate	-------
massive	massive	passive	poverty
reserve	reserve	deserve	deserve
chief	chief	sheaf	cease
lag	rag	flag	slang
pang	can	sprang	friend
encroach	encroach	reproach	reproach
rash	rice	crash	craig
skirmish	Spanish	bannish	generate
meek	meek	speak	-----
rock	rot	sock	stop
plank	tank	thank	-----
illogical	heredity	comical	comical
real	rear	steel	steel
well	----	spell	fell
gleam	gloam	seem	seem
him	hen	whim	slim
tantalizm	tantalizm	heathenism	egotism
mum	man	rum	rump

wean	wean	green	dream
specification	specification	edification	edification
stun	spun	tun	pump
drawn	-----	crown	cram
nap	not	rap	rap
rump	rant	jump	----
tubular	tubular	funicular	rediculous
spendor	splendor	splendor	breakfast
goat	goat	bloat	blowed
reject	reject	inject	deject
locket	raquet	pocket	pocket
leased	leased	feast	feet
flew	flew	grew	----
show	so	bow	row
lax	lax	sacks	stop
bay	bow	say	----

Transmitter No. III.		Transmitter No. IV.	
Given	Received	Given	Received
laid	laid	maid	paid
translucid	translucid	lucid	----
avoid	avoid	devoid	----
stupid	stupid	torpid	tempered

blindfold	blindfold	twofold	twofold
shorthand	shorthand	foreland	followed
descend	descend	to bend	to bend
around	allowed	bound	bound
inward	inward	shepherd	suffered
outface	outface	furnace	centered
instance	instance	substance	---------
applicable	applicable	improbable	infallible
execrate	execrate	generate	generate
pensive	pensive	extensive	excepted
starve	starve	observe	-------
belief	release	beef	least
brag	rare	fag	sighted
clang	-----	twang	trained
approach	approach	roach	roped
cash	traced	dash	died
ticklish	ticklish	relish	relish
beak	beak	leak	bleak
cock	cot	dock	put
sank	sunk	frank	sank
graphical	graphical	ethical	-----
kneel	seal	steel	steel

tell	tell	hell	shell
cream	cream	beam	steam
Jim	jip	Tim	Tim
parallelism	parallelism	atheism	atheism
some	sunk	glum	grub
queen	cream	seen	feed
vindication	visitation	indication	complication
spun	spent	bun	-----
town	pound	frown	frog
map	map	clap	crap
thump	thumb	hump	----
globular	globular	pupular	popular
sender	cylinder	tender	timber
float	float	coat	coat
deject	deject	subject	------
wicket	wicked	cricket	crooked
last	laughed	fast	fast
pew	pew	new	new
hoe	hoe	row	row
flax	fright	tax	cap
K	----	J	---

Transmitter V.		Transmitter VI.	
Given.	Received.	Given.	Received.
aid	spade	raid	laid
placid	sacred	candid	conduit
void	void	torrid	torrid
arid	----	cycloid	cycloid
to scold	gold	manifold	manifold
garland	----	midland	midland
commend	command	lend	lend
hound	sound	mound	mound
steward	sward	forward	forward
menace	generate	surface	------
distance	distance	clearance	------
unavoidable	unavoidable	avoidable	-------
second-rate	---------	calibrate	reach
tensive	pensive	impassive	------
subserve	observe	unnerve	unnerve
leaf	release	deaf	-------
bag	span	slag	------
rang	wind	bang	------
coach	coax	reach	--------
clash	tramp	sash	--------
hellish	hellish	Polish	Polish

peak	cease	sneak	speak
lock	lot	shock	shock
tank	dash	flank	flank
logical	logical	cynical	cynical
peal	steel	eel	eel
bell	tell	dwell	dwell
ream	bead	lean	beam
dim	dim	skin	-----
criticism	criticism	mesmerism	mesmerism
bum	bug	crumb	come
gleam	-----	beam	mean
meditation	education	modification	modification
pun	pun	run	run
renoun	renoun	brown	brown
lap	lap	gap	glass
pump	talk	chump	chump
templar	separate	circular	circular
render	------	engender	engender
boat	hope	moat	moat
object	outfit	defect	defect
thicket	----	jacket	jacket
cast	----	beast	beast

crew	true	shoe	-----
so	toe	low	low
wax	wax	six	six
A	=---	day	---

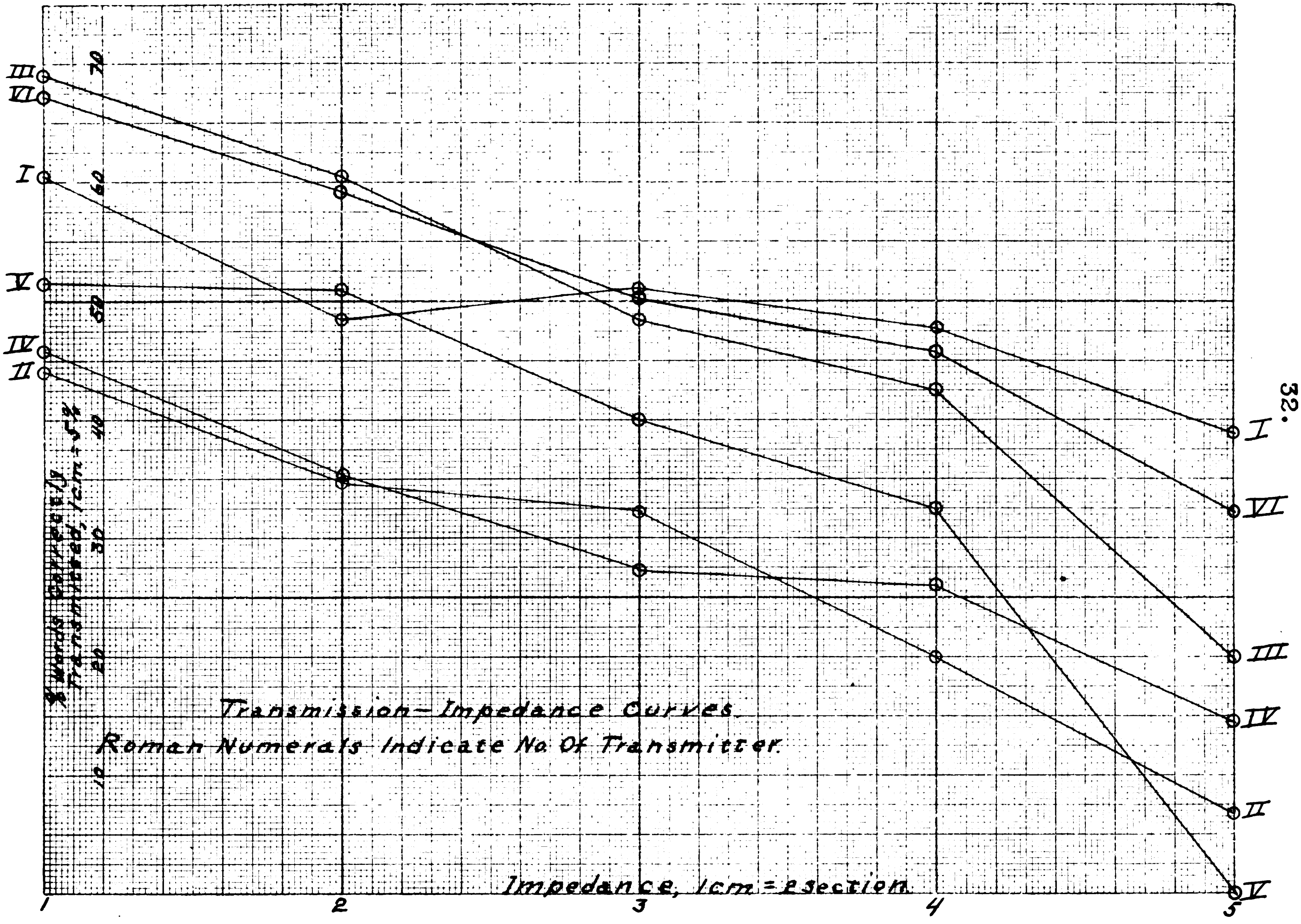
RESULT SHEET NO. I.

Line sec. No.	Transmitter No.	No. words used	Words correctly received	
			number	%
1	1	137	83	60.5
2	1	120	58	48.4
3	1	154	80	51.8
4	1	138	66	47.6
5	1	138	53	38.4
1	2	157	69	44.0
2	2	142	50	35.2
3	2	136	44	32.4
4	2	120	24	20.0
5	2	120	8	6.7
1	3	155	107	69.0
2	3	140	85	60.4
3	3	136	66	48.5
4	3	120	51	42.5
5	3	120	24	20.0
1	4	157	72	45.8
2	4	140	50	35.7
3	4	136	37	27.2
4	4	120	31	35.8

RESULT SHEET NO. I (Continued)

Line sec. No.	Trans-mitter No.	No. words used	Words correctly received number	%
5	4	120	17	14.2
1	5	157	81	51.6
2	5	141	72	51.0
3	5	136	54	39.8
4	5	120	39	32.5
5	5	120	0	0
1	6	155	104	67.1
2	6	120	71	59.2
3	6	140	71	50.7
4	6	140	64	45.7
5	6	140	45	32.2

From the above data curves on page 32 were plotted between impedance as abscissae and the percent of words correctly transmitted as ordinates.



Transmission—Impedance Curves.

Roman Numerals Indicate No. Of Transmitter.

QUALITY. The following is a description of the quality of tone of each transmitter designated by their numbers:

No. I. Over a single section the tone was too loud. As sections were added a ringing tone somewhat harsh at first gradually faded away. The tone was of extra large volume which, with the loudness and ringing for some words, made receiving very disagreeable to the ear. When all the 5 sections were in, transmission was loud, but not very clear.

No. II. Over the first few sections some words more than others caused considerable ringing which rendered them indistinct. The ringing did not cease until all 5 sections were put in. The tone was harsh and unpleasant over the first two sections, but the pitch became natural and the tone gradually softened as all sections were thrown in. Words were reproduced very faint and indistinct on the 5 sections making very slow and distinct pronunciation necessary for transmission.

No. III. No ringing sounds were heard. Tone was too loud and harsh until three sections were in when pitch became natural. Transmission was louder than No. II over 5 sections, but too faint to get good sense of reading.

No. IV. There was considerable ringing at first which

gradually disappeared as sections were thrown in. The tone was harsh, of a higher pitch than No. III but about the same loudness. When reading with all sections in only an occasional word could be distinguished.

No. V. Ringing and grating noises accompanied some words up to the fourth section when the pitch became natural. There was ample volume and loudness over four sections, but a great falling off over five sections.

No. VI. Transmission was very loud accompanied with a few ringing noises over the first section, but sense of reading was easily received over four sections. The tone had its natural pitch, was loud enough, and had sufficient volume over the five sections, yet too indistinct to get the full sense of reading. Unpleasant effects in the receiver were at no time experienced by the operator.

CONCLUSION.

By a study of the sample list of words it will be seen that many words are received so nearly correct that if used in conversation the context would make their identity evident.

Curve sheet on page 32 shows quite plainly the variation of transmission with impedance. Points only are connected; the approximate curves are left for interpolation. It is seen that No III is highest for the first two sections, but falls off rapidly until over five sections it is practically useless. In No. I there seems to be a drop on section 2, but is regained on section 3. This can be accounted for by the fact that the volume of tone was too large on small impedances to make distinct transmission. When sections 3, 4, and 5 were thrown in, curve for No. I is highest on both low and high impedances. Nos. II and IV could hardly be used over very long distances. No. V starts out quite high but fails absolutely on five sections.

The same make of transmitter as No. II is known in practice to transmit satisfactorily over at least 1,000 miles of good copper line. Since No. II falls so far below others it seems evident that a poor transmitter was obtained for the test. The same might be claimed for transmitter No. IV, however, the manufacturer claims to have

made this one especially for the test.

Since self-induction and capacity were not distributed, we can hardly conclude that these transmitters would not hold up better over practical lines of the equivalent impedances. For this reason these can only be considered as comparative tests.

APPROVED,

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